Proc. Res. Inv. NWHI
UNIHI-SEAGRANT-MR-84-01

CIGUATERA AND THE FEEDING HABITS OF THE GREATER AMBERJACK, *SERIOLA DUMERILI*, IN THE HAWAIIAN ARCHIPELAGO

Robert L. Humphreys, Jr., and Steven H. Kramer

Southwest Fisheries Center Honolulu Laboratory, National Marine Fisheries Service, NOAA, P.O. Box 3830, Honolulu, Hawaii 96812

ABSTRACT

Stomach contents collected from those greater amberjack, *Seriola dumerili*, tested for ciguatoxicity, were (1) examined to determine whether a relationship exists between feeding habits and incidence of toxicity, and (2) analyzed to determine the extent of geographic variability in the diet. Amberjack were classified into two weight groups. Large fish caught in the main Hawaiian islands fed predominantly on *Decapterus* regardless of their level of ciguatoxicity. For small amberjack, *Decap-terus* again predominated in the diet with these exceptions: those determined as being ciguatoxic and those caught in the Northwestern Hawaiian Islands. These two groups, plus the large nonciguatoxic amberjack of the Northwestern Hawaiian Islands fed more on bottom-associated fauna than all other groups studied. A series of hypotheses were generated from these results to explain the observed dietary differences.

ciguatera   Hawaiian Archipelago
amberjack   feeding habits

INTRODUCTION

Ciguatera is a toxin-related malady caused by the consumption of certain reef fishes of the tropics and subtropics. The symptoms include a variety of gastrointestinal and neurological disorders which occasionally cause death. The reef fishes involved are primarily algal and detrital feeders and higher reef predators, including some neritic predators which range into the reef environment. Virtually no evidence of toxicity exists for reef planktivores and pelagic fishes (Withers, 1982).

A source of the toxic agent, ciguatoxin, has been identified as a benthic dinoflagellate, *Gambierdiscus toxicus*, from surveys conducted by Yasumoto et al. (1977a, 1977b) of reef areas around the Gambier Islands, French Polynesia. This dinoflagellate has also been identified from Oahu, Hawaii by Taylor (1979) and found to be toxicologically similar to the Gambier Islands population (Shimizu et al., 1982).

The linkage of ciguatoxin production to *G. toxicus* supports a theory proposed by Randall (1958) which, in part, suggests that the toxin originates in the benthic reef environment. Additionally, Randall (1958) suggests that the toxin is transmitted via the food chain to fishes of higher trophic levels. The latter is supported by identification of the dinoflagellate among the gut contents of a ciguatoxic acanthurid, *Naso unicornis*, from studies by Yasumoto et al. (1977a). Although this is the only such finding to date, studies on two ciguatoxic acanthurids, *Ctenochaetus strigatus* and *Acanthurus lineatus* (Yasumoto et al., 1971), and on the ciguatoxic scarid, *Scarus gibbus* (Yasumoto et al., 1977c), revealed gut contents containing ciguatoxin. These species all belong to the lower reef trophic levels and are herbivores or detrital feeders. Fishes at these trophic levels are considered the initial accumulators of ciguatoxin; later, as prey they transmit the toxin to fishes in higher trophic levels. This pattern of transmission agrees well with documented accounts of a ciguatera outbreak at Hao Atoll, Tuamotus in 1966-68 (Banner, 1976).

Among the higher reef predators prone to be ciguatoxic is the amberjack, *Seriola dumerili*, whose distribution is worldwide in tropical and subtropical waters. In Hawaii, amberjack is found throughout the archipelago in the inner reef and outer reef slope environments. The adults are primarily found near the bottom, although they are capable of considerable vertical mobility ranging from the surface to depths of 240 m.

Dietary studies on amberjack are few and do not include any from Hawaii. Valdes-Munoz (1980) examined the stomachs (9 empty) of 21 amberjack from Cuban waters as part of a food study on 6 species implicated in ciguatera poisonings. The pomadasyid, *Haemulon sciurus*, and lutjanid, *Lutjanus synagris*, occurred most frequently in the stomachs. Randall (1967) examined 8 stomachs (2 empty) from the West Indies and found only fish as prey items including *Calamus* sp., *Caranx ruber*, *H. aurolineatum*, and *Priacanthus arenatus*. In a study of the biology and fishery of amberjack in southern Florida, Burch (1979) described the contents of 135 stomachs. Prey items occurring most frequently were lutjanids, carangids, portunids, and loligids.

Since these studies did not determine ciguatoxin levels in the amberjack sampled, little information is available on the identity of the prey species involved in ciguatoxin transmission. The opportunity to conduct such a study in Hawaii arose after a 1979 outbreak of ciguatera which implicated amberjack. This incident, coupled with previously reported cases from Hawaii and adjacent Pacific areas (Kubota, 1981) and amberjack's commercial importance in Hawaii, led to the initiation of a ciguatoxin testing program.

In this program -- involving the Southwest Fisheries Center Honolulu Laboratory of the National Marine Fisheries Service, the fishing industry, the University of Hawaii Department of Pathology, and state agencies -- flesh samples were tested for ciguatoxin levels from all amberjack delivered for sale to the United Fishing Agency (UFA) fish auction in Honolulu. Concurrently, an investigation was begun into possible dietary differences between the ciguatoxic (CTC) and non-ciguatoxic (non-CTC) amberjack. This report also includes geographical dietary comparisons among non-CTC amberjack.

METHODS

Weight, fork length, sex, and usually catch location were recorded for amberjack samples at the UFA fish auction. Only fish caught in the fishery around Penguin Bank, Kahoolawe, Lanai, Maui, and Hawaii in the lower main Hawaiian islands (LMHI) and those caught from Gardner Pinnacles to Necker bank in the Northwestern Hawaiian Islands (NWHI) were examined. These two general areas are separated by some 645 km (Figure 1). Commercial amberjack fishing was conducted primarily in depths ranging from 55 to 110 m in both areas.

Flesh samples were tested for ciguatoxin at the University of Hawaii John A. Burns School of Medicine, Pathology Department, by a radioimmunoassay (RIA) technique (Hokama et al., 1977). The toxicity levels of the fish tissues were determined from gamma radiation counts per minute per gram tissue (cpm/g) and were classified as follows: $<350{,}000$ cpm/g tissue -- negative; 350,000 to 399,999 cpm/g tissue -- borderline; and $\geq 400{,}000$ cpm/g tissue -- positive. All borderline cases were considered ciguatoxic.

Stomachs from CTC and non-CTC amberjack caught in the LMHI were collected during February 1980 to February 1981 and July 1979 to March 1980, respectively. Samples from non-CTC amberjack in the NWHI were collected during June to July 1979 and June to October 1980. No stomach samples of CTC amberjack from the NWHI were available.

Stomachs were sampled and preserved in 10 percent Formalin at the auction market. Because there was a lapse of 1 to 10 days between capture and the time the fish were brought to auction, the condition of stomach contents was often poor.

In the laboratory, stomach contents were sorted into identifiable groups. Stomachs containing only unidentifiable remains were discarded and not utilized in the study. Bait could be identified by its appearance and state of digestion. Bait and

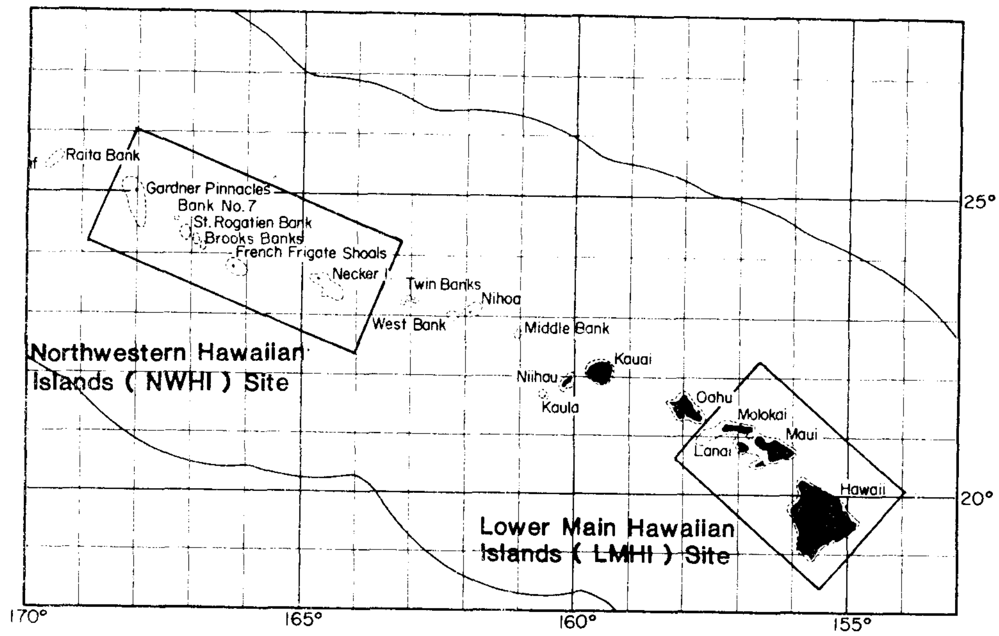


Figure 1. The two study areas of the fishery for amberjack in the Hawaiian Archipelago

parasites were recorded but not considered as food items. The volume of each food item was measured by water displacement.

Prey items were identified to lowest possible taxon. Invertebrates were digested rapidly, and frequently could be identified only to suborder. Fishes were usually identifiable to family and sometimes to species. Exceptions were the eels and flatfishes which were only identified to order. Fish in an advanced state of digestion were cleaned of flesh, stained in alizarin, and identified by vertebral count and bone morphology.

The total number (N), frequency of occurrence (F), and aggregate total volume (V) were converted to percentages to the nearest 0.1 percent for all prey taxa, and the index of relative importance (IRI) (Pinkas et al., 1971) was computed as follows:

$$IRI = \%F \times (\%N + \%V) .$$

The IRI values were rounded off to the nearest whole number. The IRI's of 0.6 to 0.9 were rounded off to 1 whereas values 0.5 and less were represented as <1. The IRI values ≥100 were considered to represent major food items.

Prey comparisons were made among class taxa and the lower identified taxa. Class comparisons offered information on the general animal types in the diet whereas lower taxa comparisons yield more specific information on the prey and diet. Prey identifiable only to class (i.e., unidentified fish, crustaceans, and cephalopods) were treated as separate entities and included in the lower taxa comparisons.

Diet was also analyzed by ecological habitat with respect to available information on the spatial distribution of prey within the Hawaiian Archipelago. The objective was to indirectly determine whether amberjack feed preferentially on bottom or midwater fauna. Three arbitrary categories were used: (1) benthic and demersal, (2) midwater and surface, and (3) combination of both habitats. This latter category includes prey which are known or suspected of inhabiting both environments equally (Natantia) and those which change habitat during larva, juvenile, or adult stage (Mullidae, Zeidae, and Tetraodontidae). Unidentified carangids, cephalopods, crustaceans, and fish were excluded from the habitat comparison.

To reduce the possibility of an artifact in dietary differences due to amberjack size alone, CTC and non-CTC amberjack were divided into two weight groups: 4.00 to 8.99 kg (small) and those >8.99 kg (large). Small amberjack were most commonly encountered during the study. Large amberjack were much less abundant but corresponded to the size commonly thought (in Hawaii) to be more frequently CTC.

RESULTS

A dietary comparison between CTC and non-CTC amberjack was investigated only within the LMHI. Among small amberjack of both these groups, the predominate class taxon in the diet was fish; crustaceans and cephalopods contributed little to the diet (Tables 1 and 2). _Decapterus_ spp. were the most important (IRI = 457) among lower taxa in the CTC group. Other major lower taxa were Teuthoidea (IRI = 246), _Symphysanodon_ _maunaloae_ (IRI = 232), crustaceans (IRI = 169), Natantia (IRI = 167), Synodontidae (IRI = 139), and Myctophidae (IRI = 118) (Figure 2, Table 1). In the non-CTC group, _Decapterus_ spp. were also the greatest contributor (IRI = 2,421) followed by Natantia (IRI = 466) and _S_. _maunaloae_ (IRI = 188) (Figure 3, Table 2).

In the diet of large amberjack, fish again predominated in both CTC and non-CTC groups with minor contributions of crustaceans and cephalopods (Tables 3 and 4). In the CTC group, _Decapterus_ spp. dominated (IRI = 1,429) among lower taxa followed by Teuthoidea (IRI = 727), Myctophidae (IRI = 177), and Engraulidae (IRI = 101) (Figure 4, Table 3). In the non-CTC group, _Decapterus_ spp. also ranked highest (IRI = 1,894) followed _Auxis_ _thazard_ (IRI = 119) (Figure 5, Table 4).

TABLE 1. PREY ITEMS OF SMALL CTC AMBERJACK FROM THE LOWER MAIN HAWAIIAN ISLANDS (N = 88) LISTED IN DECREASING IMPORTANCE BY TAXA. TAXA OF LESSER PREY (THOSE WITH IRI VALUES BELOW 100) ARE LISTED WITH THEIR RESPECTIVE IRI VALUES ONLY.

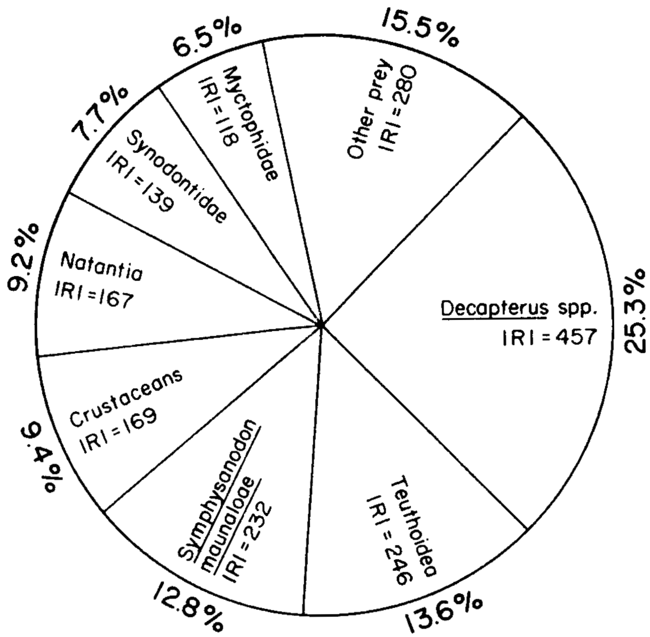
	%N	%F	%V	IRI
Taxa of prey				
Fishes	44.0	88.6	91.8	12,032
Crustaceans	38.9	29.6	4.6	1,288
Cephalopods	17.1	21.6	3.6	447
Major lower taxa prey				
Decapterus spp.	3.3	13.6	30.3	457
Teuthoidea	14.6	14.8	2.0	246
Symphysanodon maunaloae	9.0	15.9	5.6	232
Crustaceans	10.2	15.9	0.4	169
Natantia	15.1	10.2	1.3	167
Synodontidae	5.9	12.5	5.2	139
Myctophidae	5.4	18.2	1.1	118
Taxa of lesser prey				
Fish				86
Caridea				44
Octopoda				13
Pontinus macrocephala				12
Priacanthidae				12
Pomacentridae				11
Heterocarpus ensifer				8
Lutjanidae				8
Pristipomoides sp.				8
Serranidae				8
Anthias sp.				7
Auxis thazard				7
Labridae				7
Xanthichthys mento				7
Scorpaenidae				5
Mullidae				4
Reptantia				4
Selar crumenophthalmus				4
Carangidae				3
Cephalopod				3
Emmelichthyidae				2
Percophididae				2
Pleuronectiformes				2
Symphysanodon typus				2
Ammodytidae				1
Antigonia steindachneri				1
Chaetodontidae				1
Dactylopteridae				1
Grammatonotus laysanus				1
Munida sp.				1
Penaeidea				1
Plesionika longirostris				1
Plesionika sp.				1
Portunidae				1
Tetraodontidae				1
Anguilliformes				<1
Balistidae				<1
Bleekeria gilli				<1
Congridae				<1
Embolichthys sp.				<1
Engraulidae				<1
Gobiidae				<1
Paguridae				<1
Sphyraenidae				<1

Note: N = total number, F = frequency of occurrence, V = aggregate total volume, IRI = index of relative importance

TABLE 2. PREY ITEMS OF SMALL NON-CTC AMBERJACK FROM THE LOWER MAIN HAWAIIAN ISLANDS (N = 82) LISTED IN DECREASING IMPORTANCE BY TAXA. TAXA OF LESSER PREY (THOSE WITH IRI VALUES BELOW 100) ARE LISTED WITH THEIR RESPECTIVE IRI VALUES ONLY.

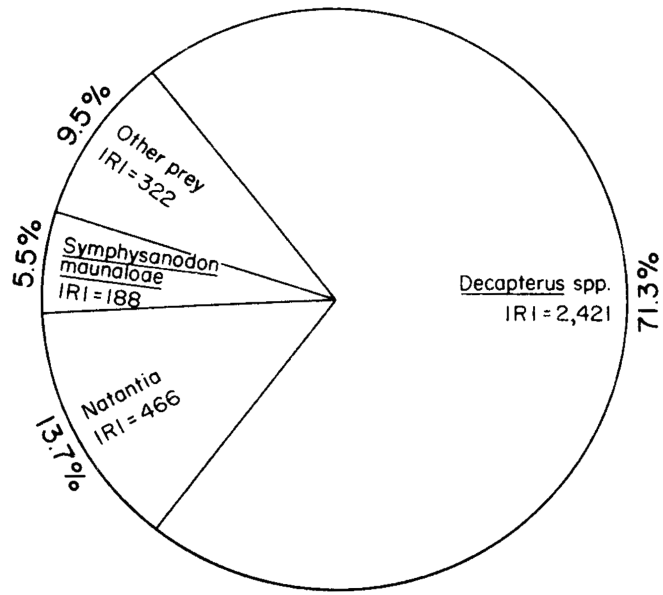
	%N	%F	%V	IRI
Taxa of prey				
Fishes	51.2	90.2	95.9	13,268
Crustaceans	43.1	22.0	2.5	1,003
Cephalopods	5.7	20.7	1.6	151
Major lower taxa prey				
Decapterus spp.	6.1	32.9	67.5	2,421
Natantia	40.6	11.0	1.8	466
Symphysanodon maunaloae	10.6	14.6	2.3	188
Taxa of lesser prey				
Teuthoidea	68	*Etelis coruscans*		3
Symphysanodon sp.	56	Bothidae		2
Fish	39	*Heterocarpus ensifer*		2
Pristipomoides sp.	19	Myctophidae		2
Crustaceans	17	Caproidae		1
Synodontidae	16	Caridea		1
Priacanthidae	14	*Decapterus macrosoma*		1
Selar crumenophthalmus	13	Lutjanidae		1
Serranidae	12	Mullidae		1
Engraulidae	10	*Scorpaenopsis* sp.		1
Emmelichthyidae	9	*Symphysanodon typus*		1
Percophididae	9	*Anthias* sp.		<1
Carangidae	8	Labridae		<1
Octopoda	6	Reptantia		<1
Tetraodontidae	6	Scorpaenidae		<1
Cephalopods	4			

Note: N = total number, F = frequency of occurrence, V = aggregate total volume, IRI = index of relative importance



Σ LOWER TAXA IRIs = 1,808
N = 88

Figure 2. Relative contribution (percent of total IRI) of lower taxa prey in the diet of small CTC amberjack from the LMHI. Taxa of lesser prey are grouped together in the "other prey" category.



Σ LOWER TAXA IRIs = 3,397
N = 82

Figure 3. Relative contribution (percent of total IRI) of prey in the diet of small non-CTC amberjack from the LMHI. Taxa of lesser prey are grouped together in the "other prey" category.

TABLE 3. PREY ITEMS OF LARGE CTC AMBERJACK FROM THE LOWER MAIN HAWAIIN ISLANDS (N = 45) LISTED IN DECREASING IMPORTANCE BY TAXA. TAXA OF LESSER PREY (THOSE WITH IRI VALUES BELOW 100) ARE LISTED WITH THEIR RESPECTIVE IRI VALUES ONLY.

	%N	%F	%V	IRI
Taxa of prey				
Fishes	67.3	95.6	98.2	15,822
Cephalopods	29.0	26.7	1.4	812
Crustaceans	3.7	6.7	0.4	27
Major lower taxa prey				
Decapterus spp.	10.5	33.3	32.4	1,429
Teuthoidea	28.4	24.4	1.4	727
Myctophidae	13.0	13.3	0.3	177
Engraulidae	22.2	4.4	0.7	101

Taxa of lesser prey			
Carangidae	73	Natantia	8
Fish	46	Pleuronectiformes	6
Balistidae	37	*Ariomma* sp.	4
Auxis rochei	26	Caridea	3
Mullidae	23	Dactylopteridae	3
Pontinus macrocephala	22	*Auxis* sp.	2
Pristipomoides sieboldii	22	*Decapterus macrosoma*	2
Tetraodontidae	19	*Heterocarpus ensifer*	2
Bothidae	13	Scombridae	2
Auxis thazard	11	Gonostomatidae	1
Priacanthidae	10	Octopoda	1
Fistulariidae	9	Synodontidae	1

Note: N = total number, F = frequency of occurrence, V = aggregate total volume, IRI = index of relative importance

TABLE 4. PREY ITEMS OF LARGE NON-CTC AMBERJACK FROM THE LOWER MAIN HAWAIIAN ISLANDS (N = 53) LISTED IN DECREASING IMPORTANCE BY TAXA. TAXA OF LESSER PREY (THOSE WITH IRI VALUES BELOW 100) ARE LISTED WITH THEIR RESPECTIVE IRI VALUES ONLY.

	%N	%F	%V	IRI
Taxa of prey				
Fishes	59.4	86.8	98.8	13,732
Crustaceans	33.5	20.8	0.5	707
Cephalopods	7.1	11.3	0.7	88
Major lower taxa prey				
Decapterus spp.	14.7	35.8	38.2	1,894
Auxis thazard	2.4	5.7	18.4	119

Taxa of lesser prey			
Lutjanidae	54	Balistidae	5
Myctophidae	54	Caridea	5
Carangidae	52	*Decapterus macrosoma*	5
Natantia	48	*Ariomma* sp.	4
Selar crumenophthalmus	41	Fistulariidae	4
Teuthoidea	41	Tetraodontidae	4
Fish	35	Cephalopods	3
Auxis sp.	32	Polymixiidae	2
Crustaceans	32	*Symphysanodon typus*	2
Reptantia	32	Synodontidae	2
Symphysanodon maunaloae	28	Labridae	1
Heterocarpus ensifer	24	Penaeidea	1
Moridae	10	Amphipoda	<1
Pristipomoides sieboldii	10	Octopoda	<1
Scorpaenidae	9	Paralepididae	<1
Lutjanus sp.	8	*Squilla* sp.	<1
Pristipomoides sp.	8	Triglidae	<1
Scombridae	6		

Note: N = total number, F = frequency of occurrence, V = aggregate total volume, IRI = index of relative importance

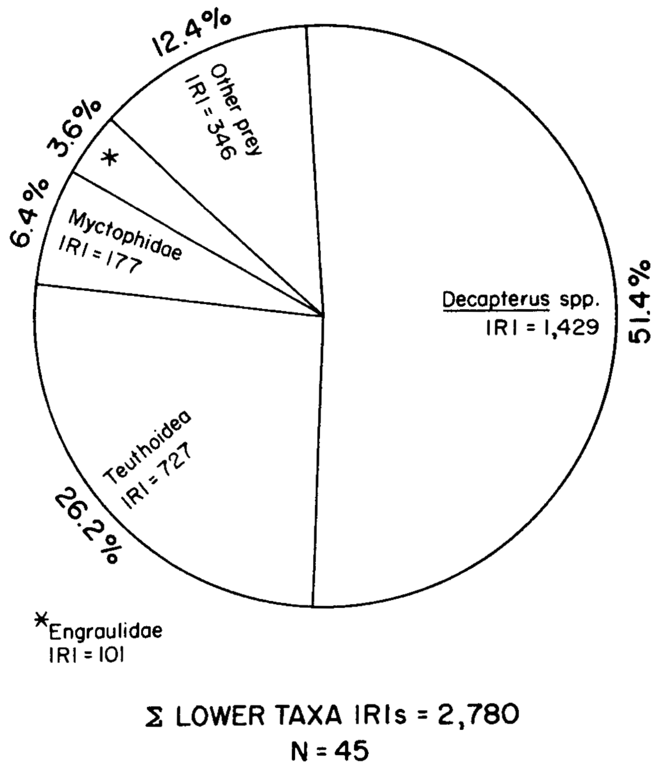


Figure 4. Relative contribution (percent of total IRI) of prey in the diet of large CTC amberjack from the LMHI. Taxa of lesser prey are grouped together in the "other prey" category.

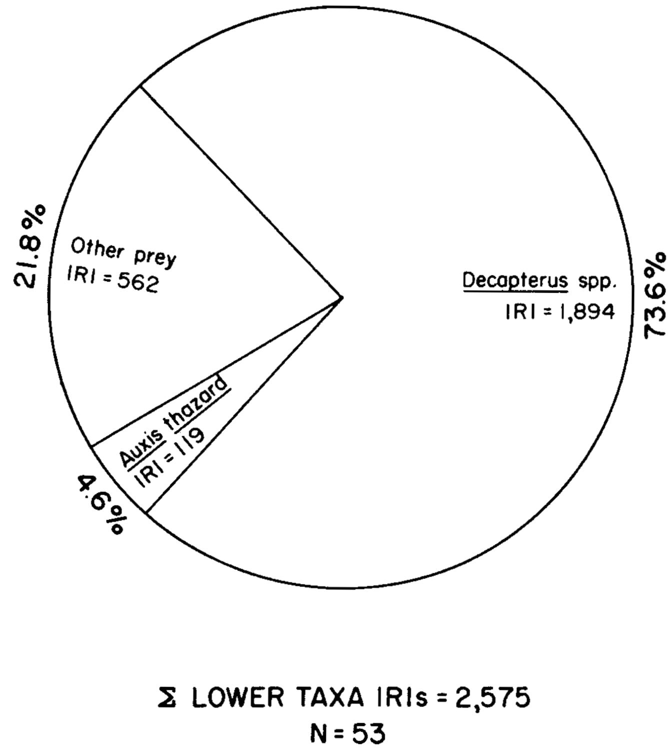


Figure 5. Relative contribution (percent of total IRI) of prey in the diet of large non-CTC amberjack from the LMHI. Taxa of lesser prey are grouped together in the "other prey" category.

The predominance of *Decapterus* spp. were similar, in terms of percentage of total IRI (Figures 3 and 5), in small and large fish of the non-CTC group. Although *Decapterus* spp. ranked highest in both weight classes of the CTC group, its percentage of total IRI among large amberjack was twice that found among the small amberjack (Figures 2 and 4). Additionally, Teuthoidea and Myctophidae appeared to be major food items in both weight classes of the CTC group, but were not present as such in either of the weight classes of the non- CTC group.

Classification of prey into ecological habitats revealed that small CTC amberjack fed more on bottom prey and midwater prey was secondary in importance (Table 5, Figure 6). The reverse situation was true among the small non-CTC amberjack (Figure 7, Table 6).

Large amberjack of both groups showed an increase in water column-associated prey and a decrease in bottom prey (Figures 8 and 9, Tables 7 and 8) compared with small amberjack (Figures 6 and 7, Tables 5 and 6), particularly within the CTC group. The small CTC amberjack were unique in having higher contributions of bottom prey than midwater prey in their diet.

The parasites found most frequently among the stomach contents of CTC and non-CTC amberjack were nematodes and trematodes. The nematode-trematode ratio ranged from 2 to 3:1 in both weight classes of the CTC and non-CTC groups.

The diet of non-CTC amberjack was compared between fish from the NWHI and the LMHI. For small amberjack in both areas, fish were the predominant class taxon and minor contributions were made by crustaceans and cephalopods (Tables 2 and 9). In the NWHI, Octopoda dominated among lower taxa (IRI = 572) followed by *Decapterus* spp. (IRI = 180), Natantia (IRI = 159), and Ammodytidae (IRI = 109) (Figure 10, Table 9). In contrast, the LMHI samples exhibited a great predominance of *Decapterus* spp. followed by Natantia and *S. maunaloae* (Figure 3, Table 2).

The most important class taxon among large amberjack in both areas was fish and less important were crustaceans and cephalopods (Tables 4 and 10). In the NWHI, *D. tabl* (IRI = 660) was the highest ranked lower taxon followed by Teuthoidea (IRI = 375), *Decapterus* spp. (IRI = 235), Balistidae (IRI = 167), fish (IRI = 164), and Tetraodontidae (IRI = 141) (Figure 11, Table 10). This contrasts with the high predominance of *Decapterus* spp. followed by *A. thazard* in the LMHI (Figure 5, Table 4).

In the NWHI Octopoda predominated among the small size class whereas *D. tabl* dominated in the large class, while in the LMHI, *Decapterus* spp. dominated among both weight classes.

TABLE 5. PREY ITEMS OF SMALL CTC AMBERJACK FROM THE LOWER MAIN HAWAIIAN ISLANDS (N = 84) GROUPED BY ECOLOGICAL HABITAT (BOTTOM, MIDWATER, AND BOTH) SHOWING THE DIETARY CONTRIBUTION (IRI) OF EACH HABITAT

Primarily bottom prey

Ammodytidae	Paguridae
Anguilliformes	Penaeidea
Anthias sp.	Percophididae
Antigonia steindachneri	Pleuronectiformes
Balistidae	Pomacentridae
Bleekeria gilli	*Pontinus macrocephala*
Chaetodontidae	Portunidae
Congridae	Priacanthidae
Dactylopteridae	*Pristipomoides* sp.
Embolichthys sp.	Reptantia
Emmelichthyidae	Scorpaenidae
Gobiidae	Serranidae
Grammatonotus laysanus	*Symphysanodon maunaloae*
Labridae	*Symphysanodon typus*
Lutjanidae	Synodontidae
Munida sp.	*Xanthichthys mento*
Octopoda	

%N	%F	%V	IRI
36.6	61.9	49.4	5,323

Primarily midwater prey

Auxis thazard	Myctophidae
Decapterus spp.	Teuthoidea
Engraulidae	

%N	%F	%V	IRI
28.4	44.0	40.5	3,032

Prey primarily associated with both habitats

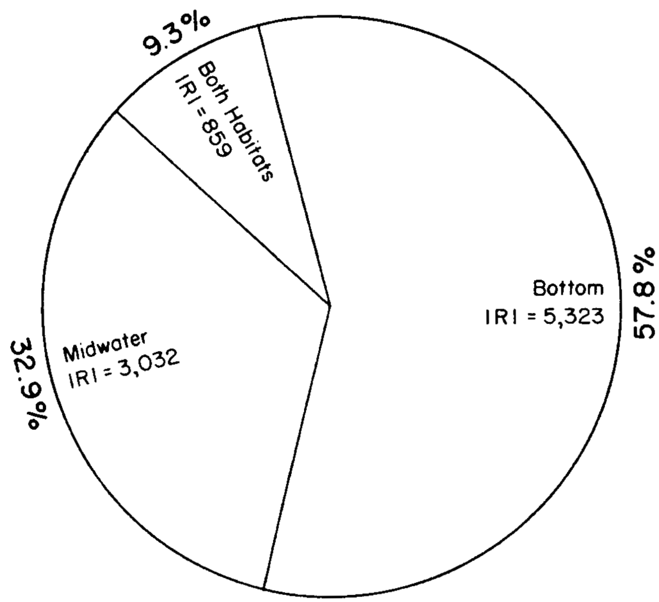
Caridea	Natantia
Heterocarpus ensifer	*Selar crumenophthalmus*
Plesionika longirostris	Sphyraenidae
Plesionika sp.	Tetraodontidae
Mullidae	

%N	%F	%V	IRI
35.1	19.0	10.1	859

Omitted prey

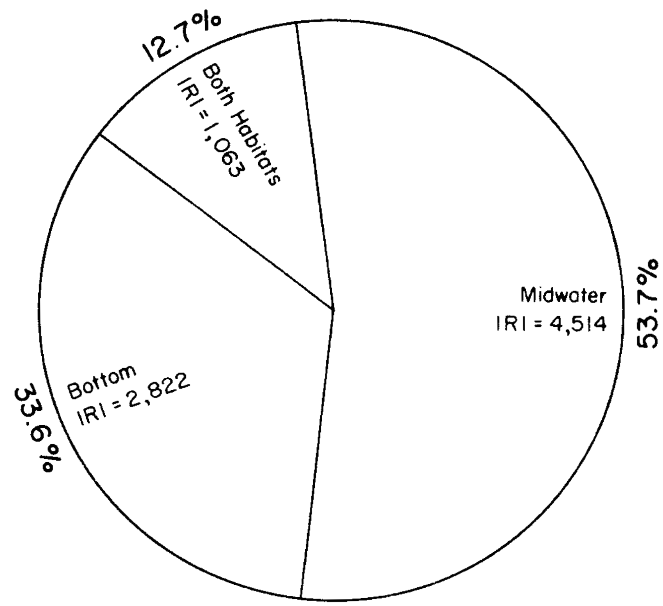
Carangidae	Crustaceans
Cephalopods	Fish

Note: N = total number, F = frequency of occurrence, V = aggregate total volume, IRI = index of relative importance



Σ IRIs = 9,214
N = 84

Figure 6. Relative contribution (percent of total IRI) of the three prey habitat types in the diet of small CTC amberjack from the LMHI



Σ IRIs = 8,399
N = 77

Figure 7. Relative contribution (percent of total IRI) of the three prey habitat types in the diet of small non-CTC amberjack from the LMHI

TABLE 6. PREY ITEMS OF SMALL NON-CTC AMBERJACK FROM THE LOWER MAIN HAWAIIAN ISLANDS (N = 77) GROUPED BY ECOLOGICAL HABITAT (BOTTOM, MIDWATER, AND BOTH) SHOWING THE DIETARY CONTRIBUTION (IRI) OF EACH HABITAT

Primarily bottom prey

Anthias sp.
Bothidae
Caproidae
Emmelichthyidae
Etelis coruscans
Labridae
Lutjanidae
Octopoda
Percophididae
Priacanthidae
Pristipomoides sp.
Reptantia
Scorpaenidae
Scorpaenopsis sp.
Serranidae
Symphysanodon maunaloae
Symphysanodon sp.
Symphysanodon typus
Synodontidae

%N	%F	%V	IRI
39.3	48.0	19.5	2,822

Primarily midwater prey

Decapterus macrosoma
Decapterus spp.
Engraulidae
Myctophidae
Teuthoidea

%N	%F	%V	IRI
15.9	52.0	70.9	4,514

Prey primarily associated with both habitats

Caridea
Heterocarpus ensifer
Mullidae
Natantia
Selar crumenophthalmus
Tetraodontidae

%N	%F	%V	IRI
44.9	19.5	9.6	1,063

Omitted prey

Carangidae
Cephalopods
Crustaceans
Fish

Note: N = total number, F = frequency of occurrence, V = aggregate total volume, IRI = index of relative importance

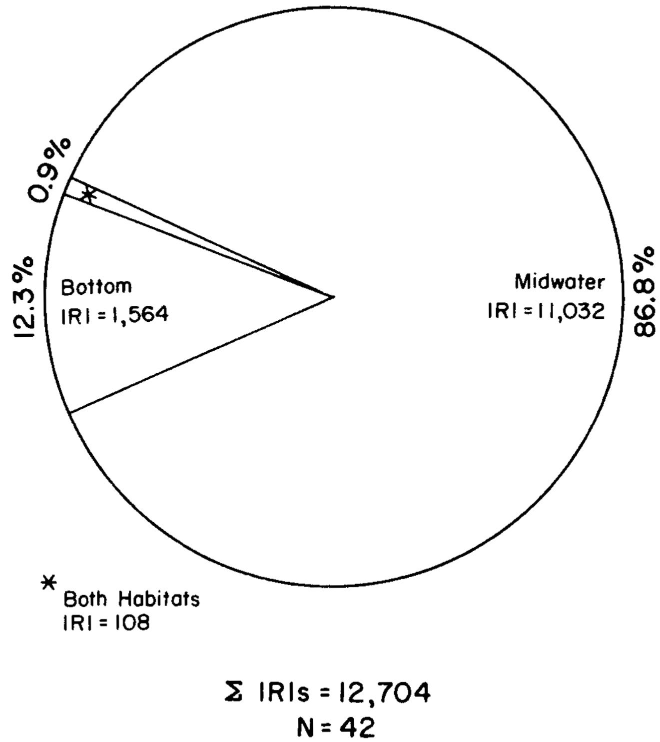


Figure 8. Relative contribution (percent of total IRI) of the three prey habitat types in the diet of large CTC amberjack from the LMHI

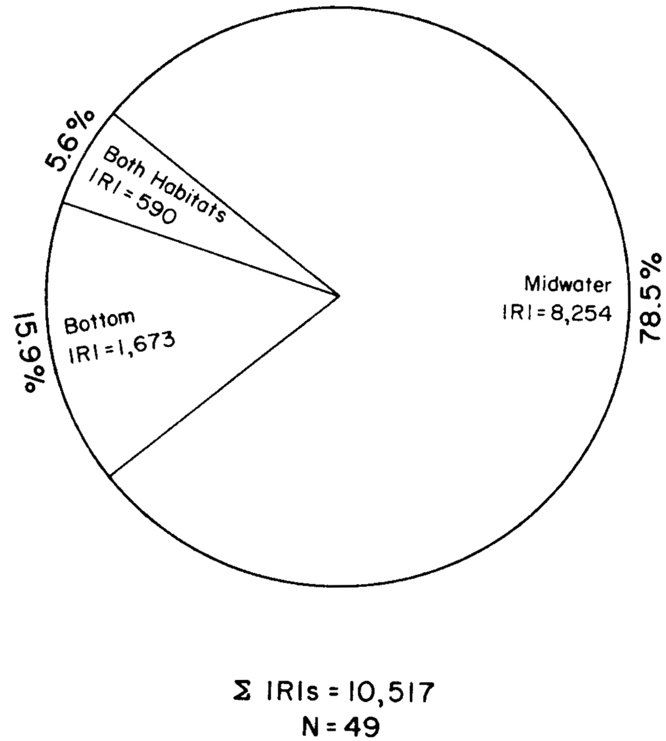


Figure 9. Relative contribution (percent of total IRI) of the three prey habitat types in the diet of large non-CTC amberjack from the LMHI

TABLE 7. PREY ITEMS OF LARGE CTC AMBERJACK FROM THE LOWER MAIN HAWAIIAN ISLANDS (N = 42) GROUPED BY ECOLOGICAL HABITAT (BOTTOM, MIDWATER, AND BOTH) SHOWING THE DIETARY CONTRIBUTION (IRI) OF EACH HABITAT

Primarily bottom prey

Balistidae
Bothidae
Dactylopteridae
Fistulariidae
Mullidae
Octopoda
Pleuronectiformes
Pontinus macrocephala
Priacanthidae
Pristipomoides sieboldii
Synodontidae

%N	%F	%V	IRI
9.9	28.6	44.8	1,564

Primarily midwater prey

Ariomma sp.
Auxis rochei
Auxis sp.
Auxis thazard
Decapterus macrosoma
Decapterus spp.
Engraulidae
Gonostomatidae
Myctophidae
Scombridae
Teuthoidea

%N	%F	%V	IRI
84.2	81.0	52.0	11,032

Prey primarily associated with both habitats

Caridea
Heterocarpus ensifer
Natantia
Tetraodontidae

%N	%F	%V	IRI
5.9	11.9	3.2	108

Omitted prey

Carangidae
Fish

Note: N = total number, F = frequency of occurrence, V = aggregate total volume, IRI = index of relative importance

TABLE 8. PREY ITEMS OF LARGE NON-CTC AMBERJACK FROM THE LOWER MAIN HAWAIIAN ISLANDS (N = 49) GROUPED BY ECOLOGICAL HABITAT (BOTTOM, MIDWATER, AND BOTH) SHOWING THE DIETARY CONTRIBUTON (IRI) OF EACH HABITAT

Primarily bottom prey

Balistidae
Fistulariidae
Labridae
Lutjanidae
Lutjanus sp.
Moridae
Octopoda
Penaeidea
Polymixiidae
Pristipomoides sieboldii
Pristipomoides sp.
Reptantia
Scorpaenidae
Symphysanodon maunaloae
Symphysanodon typus
Synodontidae
Triglidae

%N	%F	%V	IRI
26.3	34.7	21.9	1,673

Primarily midwater prey

Amphipoda
Auxis sp.
Auxis thazard
Ariomma sp.
Decapterus macrosoma
Decapterus spp.
Myctophidae
Paralepididae
Scombridae
Squilla sp.
Teuthoidea

%N	%F	%V	IRI
43.4	71.4	72.2	8,254

Prey primarily associated with both habitats

Caridea
Heterocarpus ensifer
Natantia
Selar crumenophthalmus
Tetraodontidae

%N	%F	%V	IRI
30.3	16.3	5.9	590

Omitted prey

Carangidae
Cephalopods
Crustaceans
Fish

Note: N = total number, F = frequency of occurrence, V = aggregate total volume, IRI = index of relative importance

TABLE 9. PREY ITEMS OF SMALL NON-CTC AMBERJACK FROM THE NORTHWESTERN HAWAIIAN ISLANDS (N = 92) LISTED IN DECREASING IMPORTANCE BY TAXA. TAXA OF LESSER PREY (THOSE WITH IRI VALUES BELOW 100) ARE LISTED WITH THEIR RESPECTIVE IRI VALUES ONLY.

	%N	%F	%V	IRI
Taxa of prey				
Fishes	60.6	82.6	66.3	10,482
Cephalopods	8.7	25.0	31.1	995
Crustaceans	30.7	13.0	2.6	433
Major lower taxa prey				
Octopoda	4.9	16.3	30.2	572
Decapterus spp.	2.6	10.9	13.9	180
Natantia	27.6	5.4	1.9	159
Ammodytidae	11.2	7.6	3.2	109

Taxa of lesser prey			
Serranidae	81	Carangidae (jack)	2
Fish	73	*Scomber japonicus*	2
Teuthoidea	45	Fistulariidae	1
Anthias sp.	44	Mullidae	1
Emmelichthyidae	40	Ostraciontidae	1
Tetraodontidae	40	Penaeidea	1
Priacanthidae	36	Percophididae	1
Embolichthys sp.	25	Acanthuridae	<1
Pseudomonocanthus garretti	18	Argentinidae	<1
		Bleekeria gilli	<1
Symphysanodon maunaloae	17	Bothidae	<1
		Bramidae	<1
Congridae	16	Cephalopods	<1
Decapterus tabl	15	Dactylopteridae	<1
Crustaceans	11	Euphausiacea	<1
Ariomma sp.	6	Exocoetidae	<1
Synodontidae	6	Moridae	<1
Balistidae	4	Nomeidae	<1
Myctophidae	4	Pegasidae	<1
Pleuronectiformes	4	*Psenes* sp.	<1
Symphysanodon typus	4	Reptantia	<1
Anguilliformes	2	Scorpaenidae	<1
Aracana aculeata	2	Triglidae	<1
Caproidae	2	Zeidae	<1

Note: N = total number, F = frequency of occurrence, V = aggregate total volume, IRI = index of relative importance

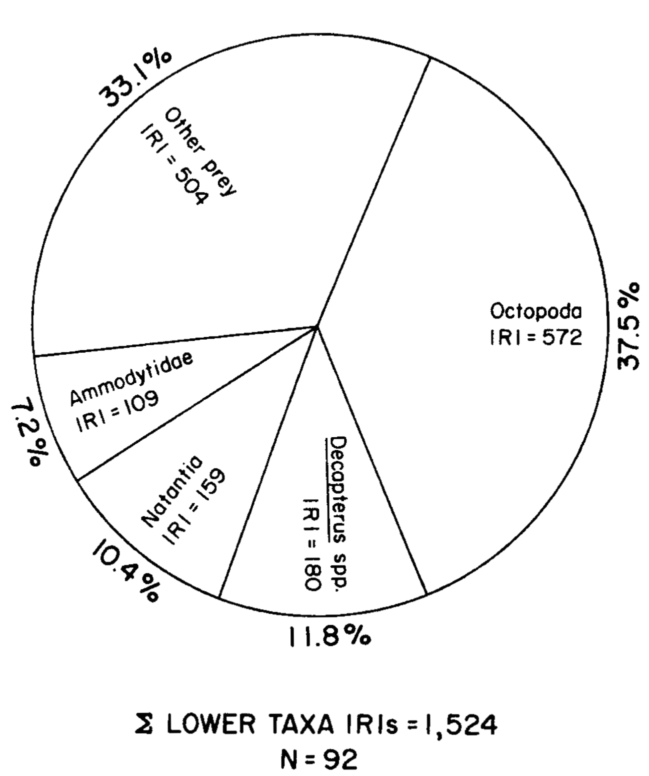


Figure 10. Relative contribution (percent of total IRI) of prey in the diet of small non-CTC amberjack from the NWHI. Taxa of lesser prey are grouped together in the "other prey" category.

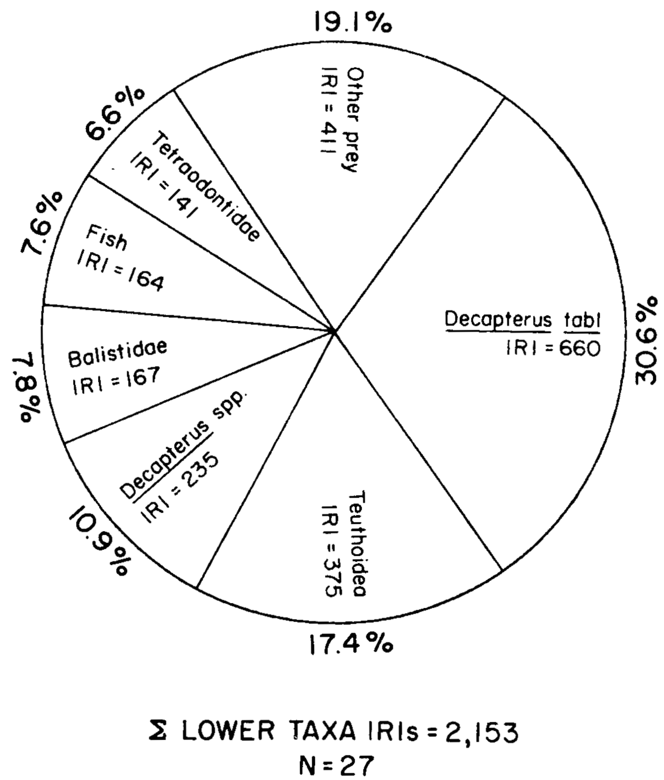


Figure 11. Relative contribution (percent of total IRI) of prey in the diet of large non-CTC amberjack from the NWHI. Taxa of lesser prey are grouped together in the "other prey" category.

TABLE 10. PREY ITEMS OF LARGE NON-CTC AMBERJACK FROM THE NORTHWESTERN HAWAIIAN ISLANDS (N = 27) LISTED IN DECREASING IMPORTANCE BY TAXA. TAXA OF LESSER PREY (THOSE WITH IRI VALUES BELOW 100) ARE LISTED WITH THEIR RESPECTIVE IRI VALUES ONLY.

	%N	%F	%V	IRI
Taxa of prey				
Fishes	58.2	77.8	96.2	12,012
Cephalopods	20.9	33.3	3.1	799
Crustaceans	20.9	18.5	0.7	400
Major lower taxa prey				
Decapterus tabl	9.9	14.8	34.7	660
Teuthoidea	16.5	22.2	0.4	375
Decapterus spp.	5.5	14.8	10.4	235
Balistidae	12.1	7.4	10.5	167
Fish	6.6	22.2	0.8	164
Tetraodontidae	3.3	11.1	9.4	164

Taxa of lesser prey			
Pseudomonocanthus garretti	82	*Symphysanodon maunaloae*	8
Octopoda	79	Carangidae	6
Fistulariidae	75	Polymixiidae	6
Crustaceans	64	Priacanthidae	6
Reptantia	37	Anguilliformes	4
Muraenidae	14	Argentinidae	4
Congridae	9	Natantia	4
Mullidae	9	Synodontidae	4

Note: N = total number, F = frequency of occurrence, V = aggregate total volume, IRI = index of relative importance

The results of habitat classification of prey revealed that among small NWHI amberjack, bottom-associated prey was most important (Table 11, Figure 12), whereas for small LMHI amberjack, the water column-associated prey dominated (Figure 7, Table 6). For large NWHI amberjack, bottom prey ranked higher than midwater prey (Figure 13, Table 12). However, the large LMHI amberjack showed a predominance of midwater prey (Figure 9, Table 8).

The dietary change from small to large amberjack in both areas involved an increase of midwater prey and a decrease in bottom prey.

Nematodes and trematodes were the most frequent gut parasites, regardless of weight class and area. The ratio of nematodes to trematodes for the NWHI sample ranged from 3 to 4:1 compared with 2 to 3:1 for the LMHI sample.

TABLE 11. PREY ITEMS OF SMALL NON-CTC AMBERJACK FROM THE NORTHWESTERN HAWAIIAN ISLANDS (N = 85) GROUPED BY ECOLOGICAL HABITAT (BOTTOM, MIDWATER, AND BOTH) SHOWING THE DIETARY CONTRIBUTION (IRI) OF EACH HABITAT

Primarily bottom prey

Acanthuridae	Octopoda
Ammodytidae	Ostraciontidae
Anguilliformes	Pegasidae
Anthias sp.	Penaeidea
Aracana aculeata	Percophididae
Balistidae	Pleuronectiformes
Bleekeria gilli	Priacanthidae
Bothidae	*Pseudomonocanthus garretti*
Caproidae	Reptantia
Carangidae	*Scomber japonicus*
Congridae	Scorpaenidae
Dactylopteridae	Serranidae
Embolichthys sp.	*Symphysanodon maunaloae*
Emmelichthyidae	*Symphysanodon typus*
Fistulariidae	Synodontidae
Moridae	Triglidae

%N	%F	%V	IRI
53.6	74.1	71.1	9,240

Primarily midwater prey

Argentinidae	Exocoetidae
Ariomma sp.	Myctophidae
Bramidae	Nomeidae
Decapterus spp.	*Psenes* sp.
Decapterus tabl	Teuthoidea

%N	%F	%V	IRI
9.3	36.5	23.2	1,186

Prey primarily associated with both habitats

Euphausiacea	Tetraodontidae
Mullidae	Zeidae
Natantia	

%N	%F	%V	IRI
37.1	14.1	5.7	603

Omitted prey

Cephalopods	Fish
Crustaceans	

Note: N = total number, F = frequency of occurrence, V = aggregate total volume, IRI = index of relative importance

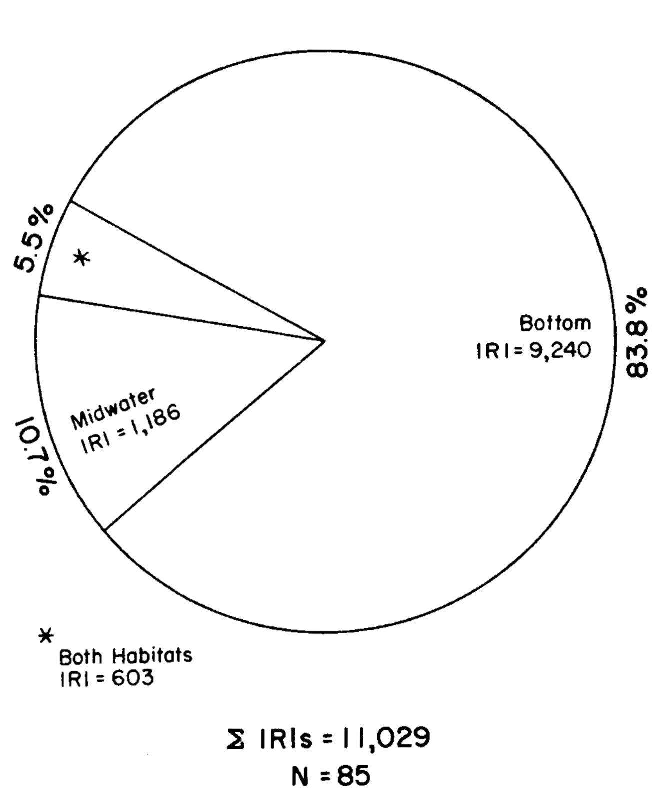


Figure 12. Relative contribution (percent of total IRI) of the three prey habitat types in the diet of small non-CTC amberjack from the NWHI

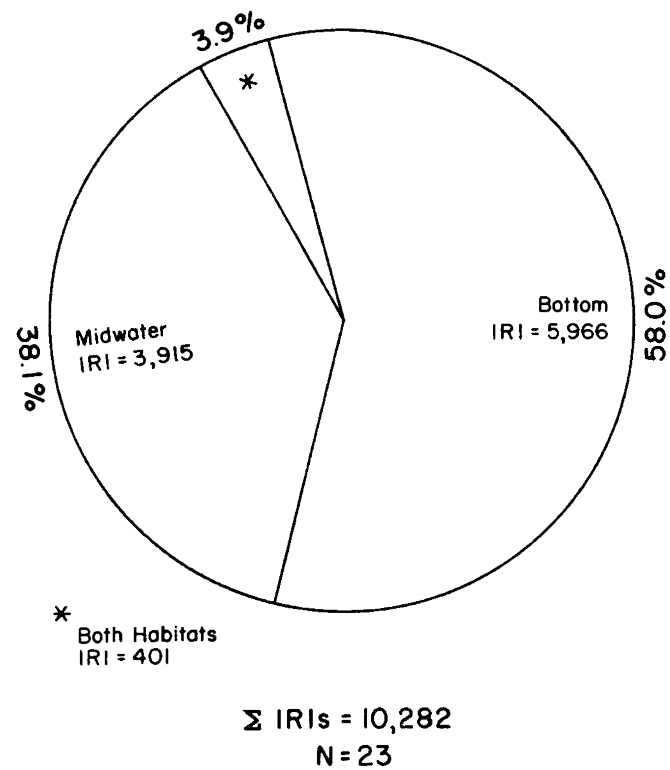


Figure 13. Relative contribution (percent of total IRI) of the three prey habitat types in the diet of large non-CTC amberjack from the NWHI

TABLE 12. PREY ITEMS OF LARGE NON-CTC AMBERJACK FROM THE NORTHWESTERN HAWAIIAN ISLANDS (N = 23) GROUPED BY ECOLOGICAL HABITAT (BOTTOM, MIDWATER, AND BOTH) SHOWING THE DIETARY CONTRIBUTION (IRI) OF EACH HABITAT

Primarily bottom prey

Anguilliformes	Polymixiidae
Balistidae	Priacanthidae
Congridae	*Pseudomonocanthus garretti*
Fistulariidae	Reptantia
Muraenidae	*Symphysanodon maunaloae*
Octopoda	Synodontidae

%N	%F	%V	IRI
47.8	65.2	43.7	5,966

Primarily midwater prey

Argentinidae	*Decapterus tabl*
Decapterus spp.	Teuthoidea

%N	%F	%V	IRI
43.5	43.5	46.5	3,915

Prey primarily associated with both habitats

Mullidae	Tetraodontidae
Natantia	

%N	%F	%V	IRI
8.7	21.7	9.8	401

Omitted prey

Carangidae	Fish
Crustaceans	

Note: N = total number, F = frequency of occurrence, V = aggregate total volume, IRI = index of relative importance

DISCUSSION

Decapterus spp. were the most important lower prey taxon in the diet of LMHI amberjack, regardless of their toxicity or size. *Decapterus* spp. were also the most important component among the midwater prey which dominated in the non-CTC and large CTC amberjack. Among small CTC amberjack, however, *Decapterus* spp. were less predominant and this was reflected in the higher contribution of bottom prey as opposed to midwater prey. Therefore, dietary differences between the small CTC amberjack and the other three groups are primarily reflected in the smaller contribution of *Decapterus* spp. in the former group. To help understand the dietary differences observed thus far in relation to whether

Decapterus spp. might be involved in the transmission of ciguatoxin, the following pertinent information is summarized.

The genus Decapterus is represented by four species within the Hawaiian Archipelago. Decapterus macarellus is the most abundant species in the LMHI but in the NWHI their abundance is unknown. In this paper this species is called Decapterus spp. because D. macarellus and D. muroadsi (an infrequent conspecific), are not readily distinguishable. The other two species, D. macrosoma and D. tabl, are easily distinguishable from each other as well as from Decapterus spp.

A life history study by Yamaguchi (1953) characterized D. macarellus as usually inhabiting the middle and upper layers of the neritic zone, although at times being found in shallow water and far out at sea. Yamaguchi concluded that D. macarellus fed on zooplankton, primarily crustaceans. Dietary studies on other members of the genus, including D. tabl, showed them to be primarily planktivorous (Tiews et al., 1970). This feeding mode among members of Decapterus indicates little interaction with benthic fauna. Assuming that ciguatoxin has a benthic origin in the LMHI, similar to what Yasumoto et al. (1977a, 1977b) found in French Polynesia, Decapterus appears to be an unlikely intermediary for ciguatoxin transmission through the food chain. Additionally, Decapterus is a popular food fish in Hawaii, yet Kubota (1981) found no instances of it being implicated among reported ciguatera poisoning cases from 1900 to December 1980. From this background information, several hypotheses have been developed to explain the dietary patterns found among the four groups investigated in the LMHI.

For amberjack, a temporal and spatial change of available prey would prevail when Decapterus is absent or scarce. In this situation the most abundant prey would then be bottom forms because Decapterus appears to be the only abundant midwater prey in the diet. If this switch to feeding on bottom prey coincided with ciguatoxicity among the local reef fauna, the link in the transmission of ciguatoxin would be completed. This chain of events would explain the lower Decapterus, higher bottom prey tendencies that occur in the small CTC amberjack. It is also assumed that large CTC and non-CTC amberjack possess increased mobility and speed, thus enhancing their ability to capture and consume larger and faster midwater prey. This is evident by the large amounts of Decapterus and the occurrence of Auxis in their diet. Hence, large amberjack are probably less apt to feed on bottom prey if midwater prey are readily available. Kimura et al. (1981) found that large amberjack had the same incidence of ciguatoxicity as small ones for the LMHI and NWHI areas combined. Thus ciguatoxin appears more likely to be transmitted to small rather than large amberjack. Ciguatoxicity in large amberjack is likely attributable to the retention of ciguatoxin from an earlier exposure. Although ciguatoxin retention in kahala has not been investigated, Banner et al. (1966) did conduct such a study on the reef carnivore, Lutjanus bohar, from Christmas

Island. Results indicated that no statistically detectable losses in toxicity occurred among a group of L. bohar held in captivity at Coconut Island, Oahu, Hawaii for up to 30 months. Banner et al. did qualify their results, however, by suggesting that the toxicity level in some ciguatoxic fish may gradually diminish over time.

These hypotheses, however, appear to be contradicted by the NWHI amberjack. The diet of small non-CTC amberjack in the NWHI contains more bottom prey than that of the small CTC amberjack in the LMHI. With greater feeding of amberjack on bottom prey, the incidence of ciguatoxicity among amberjack in the NWHI would be expected to be higher than the toxicity rate determined for the LMHI fish. However, Polovina and Ito (1981) found no apparent relationship between incidence of toxicity and area. It therefore appears plausible, as shown by Yasumoto et al. (1979) in the overall higher population counts of G. toxicus at Gambier Islands compared with Tahiti, that the NWHI offer less suitable conditions for ciguatoxin outbreaks than the LMHI. If this situation is true, then the increased utilization of bottom prey by NWHI amberjack would not necessarily cause a greater incidence of ciguatoxicity when compared with the LMHI. Still unaccounted for is the reason for the increase in bottom prey in both weight groups in the NWHI, when Decapterus is known to occur there, perhaps in great abundance. The high occurrence of Octopoda in the diet of the small NWHI amberjack is the only instance of a lower prey taxon exceeding Decapterus spp. and D. tabl in percentage of total IRI. By comparison, Octopoda in all four groups in the LMHI is consistently negligible. It thus appears plausible that sufficient readily available bottom prey exists within the NWHI such that midwater prey, namely Decapterus, are fed upon less often by the small amberjack. Even so, the trend toward increased midwater prey in the diet as the amberjack grows larger in the LMHI is also evident in the NWHI, although to a lesser degree. This trend apparently indicates that the large NWHI amberjack are increasingly capable of consuming the swifter and frequently larger midwater prey, a situation more strongly indicated by their weight class counterparts in the LMHI.

CONCLUSIONS

Data presented in this report support the hypothesis that small amberjack in the LMHI are more susceptible to becoming ciguatoxic when feeding preference shifts away from Decapterus to bottom prey. Since large amberjack feed more on Decapterus, the occurrence of large CTC amberjack is mainly attributed to ciguatoxin's long retention time. The data also suggest that a more readily available bottom prey fauna exists in the NWHI and that conditions for CTC outbreaks are less than optimal there compared with the LMHI. Tests of these hypotheses should address the following: determination of ciguatoxicity in Decapterus and bottom prey species over time and area; diet of CTC amberjack from the NWHI; retention time of ciguatoxin in amberjack; confirmation of a solely benthic mode of ciguatera origin and, if so, the determination of population abundance of the ciguatoxin-producing agent in the NWHI and LMHI.

REFERENCES

Banner, A.H., P. Helfrich, and T. Piyakarnchana. 1966. Retention of ciguatera toxin by the red snapper, Lutjanus bohar. Copeia (2):297-301.

Banner, A.H. 1976. Ciguatera: A disease from coral reef fish. In Biology and Geology of Coral Reefs, ed. O.A. Jones, and R. Endean, Volume III: Biology 2, pp. 177-213. New York: Academic Press.

Burch, R.K. 1979. The greater amberjack, Seriola dumerili: Its biology and fishery off southeastern Florida. M.S. thesis, University of Miami, Florida.

Hokama, Y., A.H. Banner, and D.B. Boylan. 1977. A radioimmunoassay for the detection of ciguatoxin. Toxicon 15:317-325.

Kimura, L.H., M.A. Abad, and Y. Hokama. Evaluation of the radioimmunoassay (RIA) for detection of ciguatera (CTX) in fish tissues. Paper presented at Pacific Ciguatera Workshop, March 18-20, 1981, Honolulu, Hawaii. University of Hawaii School of Medicine, Honolulu. 14 pp.

Kubota, W. 1981. Ciguatera fish poisoning cases: A summary from 1900-December 1980. Paper presented at Pacific Ciguatera Workshop, March 18-20, 1981, Honolulu, Hawaii, various paging. National Marine Fisheries Service, NOAA, P.O. Box 3830, Honolulu, Hawaii.

Pinkas, L., M.S. Oliphant, and I.L.K. Iverson. 1971. Food habits of albacore, bluefin tuna, and bonito in California waters. California Department of Fish and Game, Fish Bulletin 152, 105 pp.

Polovina, J.J., and B.M. Ito. 1981. An analysis of data from the kahala ciguatera sampling program, April 1979-December 1980. Paper presented at Pacific Ciguatera Workshop, March 18-20, 1981, Honolulu, Hawaii. 4 pp.

Randall, J.E. 1958. A review of ciguatera, tropical fish poisoning, with a tentative explanation of its cause. Bulletin of Marine Science of the Gulf and Carribbean 8(3):236-267.

Randall, J.E. 1967. Food habits of reef fishes of the West Indies. In Studies in Tropical Oceanography, No. 5, pp. 665-847. University of Miami, Florida.

Shimizu, Y., H. Shimizu, P.J. Scheuer, Y. Hokama, M. Oyama, and J.T. Miyahara. 1982. Gambierdiscus toxicus, a ciguatera-causing dinoflagellate from Hawaii. Bulletin of the Japanese Society of Scientific Fisheries 48(6):811-813.

Taylor, F.J.R. 1979. A description of the benthic dinoflagellate associated with maitotoxin and ciguatoxin, including observations on Hawaiian material. In Toxic Dinoflagellate Blooms, ed. D.L. Taylor, and H.H. Seliger, pp. 71-76. New York: Elsevier North Holland, Inc.

Tiews, K., I.A. Ronquillo, and P. Caces-Borja. 1970. On the biology of roundscads (Decapterus Bleeker) in the Philippine waters. In Proceedings, Indo-Pacific Fisheries Council 13(2):82-106.

Valdes-Munoz, E. 1980. Toxicidad y alimentacion de algunos peces sospechosos de provocar la ciguatera. (In Spanish, English abstract). Informe Cientifico-Tecnico 123, 16 pp.

Withers, N.W. 1982. Ciguatera fish poisoning. Annual Review of Medicine 33:97-111.

Yamaguchi, Y. 1953. The fishery and the biology of the Hawaiian opelu, Decapterus pinnulatus (Eydoux and Souleyet). M.S. thesis, University of Hawaii, Honolulu.

Yasumoto, T., Y. Hashimoto, R. Bagnis, J.E. Randall, and A.H. Banner. 1971. Toxicity of the surgeonfishes. Bulletin of the Japanese Society of Scientific Fisheries 37(8):724-734.

Yasumoto, T., R. Bagnis, S. Thevenin, and M. Garcon. 1977a. A survey of comparative toxicity in the food chain of ciguatera. Bulletin of the Japanese Society of Scientific Fisheries 43(8):1015-1019.

Yasumoto, T., I. Nakajima, R. Bagnis, and R. Adachi. 1977b. Finding of a dinoflagellate as a likely culprit of ciguatera. Bulletin of the Japanese Society of Scientific Fisheries 43(8):1021-1026.

Yasumoto, T., I. Nakajima, E. Chungue, and R. Bagnis. 1977c. Toxins in the gut contents of parrotfish. Bulletin of the Japanese Society of Scientific Fisheries 43(1):69-74.

Yasumoto, T., A. Inoue, R. Bagnis, and M. Garcon. 1979. Ecological survey of a dinoflagellate possibly responsible for the induction of ciguatera. Bulletin of the Japanese Society of Scientific Fisheries 45(3):395-399.